The population of GRB hosts

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Abstract

The properties of their hosts provide important clues to the progenitors of different classes of gamma-ray bursts (GRBs). The hosts themselves also constitute a sample of high-redshift star-forming galaxies which, unlike most other methods, is not selected on the luminosities of the galaxies themselves. We discuss what we have learnt from and about GRB host galaxies to date.

Key words:

1 Introduction

Pinpointing the first long-duration GRB afterglows quickly resolved the debate over their distance scale (van Paradijs *et al.*, 1997; Metzger *et al.*, 1997), and the realisation that their hosts were high-redshift star-forming galaxies was one of the first pieces of evidence suggesting their progenitors were massive stars (Paczynski, 1998).

Subsequently, the characteristics of their (likely) host galaxies have formed an equally important line of argument regarding the nature of the short-duration bursts (Gehrels *et al.*, 2005; Hjorth *et al.*, 2005; Bloom *et al.*, 2006).

In addition to helping understand GRBs themselves, hosts are becoming increasingly important as a high-redshift population selected only by its star forming properties, and not dependent on the luminosity of individual galaxies, which is the case for most other samples.

In this contribution we discuss the latest developments in our understanding of the population of GRB hosts, and consider likely future directions.

2 Long-duration bursts

As mentioned above, the fact that no long-duration bursts (LGRBs) have been found in early-type galaxies was a strong argument in favour of their association with massive star death. The question naturally arises exactly what properties a star must have in order to produce a GRB at the end of its life. This is related to the important question of whether the properties, rate and/or luminosity, of GRBs depends on the characteristics of the stellar populations which produce them. In particular, if GRB properties depend on the chemical makeup of their progenitor stars, or other aspects of its galactic environment, that will influence the statistical properties of the sample of host galaxies they select.

2.1 GRBs and metallicity

In the popular "collapsar" model for the production of GRBs, it has been argued that high (around solar and above) metallicity single Wolf-Rayet stars will lose too much mass and angular momentum to produce the rapidly rotating massive cores that ultimately collapse to produce GRBs (Heger *et al.*, 2003).

A number of observational studies are consistent with the idea that GRBs are preferentially produced by stellar populations that are at least moderately poor (sub-solar) in heavy metals. Fynbo *et al.* (2003) first noted that the high proportion of GRB host galaxies above redshift $z \approx 2$ that show Lyman-α in emission suggests they are low dust, low metal systems. Subsequently, studies of samples of GRB host galaxies in the mid- and far-IR and submm (Berger *et al.*, 2003; Tanvir *et al.*, 2004; Le Floc'h *et al.*, 2006; Castro Cerón *et al.*, 2006) have found fewer hosts are bright in these bands than expected, given the large amount of obscured star formation expected to be taking place in such galaxies. Again, a preference for lower metallicities would help explain this finding if the very high star-formation rate galaxies correspond to higher metallicity systems as is thought. Note there is potentially a selection effect here, since some GRB hosts will not be identified in the first place if the optical light of the GRB is extinced by dust. However, several such "dark bursts" have sufficiently good positions to identify their hosts, and were included in the samples studied (eg. Barnard *et al.*, 2003). A similar argument has been made for the five lowest redshift GRBs, which are

all in rather small, metal-poor galaxies when compared to the population of low-z star-forming galaxies (Stanek *et al.*, 2006).

Most recently, Fruchter *et al.* (2006) compared the host galaxies of GRBs and core-collapse supernovae in a similar redshift range, roughly $z = 0.5$–1 (the average and spread of redshift was also similar between the two). The characteristics of the galaxies and also the positions of the exploding stars, differed significantly between the samples. In figures 1 and 2 we show somewhat updated mosaics of the GRB and SNe hosts respectively. The supernova hosts are clearly more likely to be brighter, frequently grand-design spirals, while the GRB hosts are typically smaller and have irregular/merger morphologies (see also Conselice *et al.*, 2005; Wainwright, Berger, & Penprase, 2007). This could also be explained if the GRBs are preferentially formed from lower-metallicity core-collapse supernovae. A bias against finding GRBs enshrouded in dusty systems should be more than matched by the same bias against finding supernovae hidden by dust (recalling that GRBs can burn through significant columns of intervening dust and so may sometimes be found optically even when enshrouded (eg. Waxman & Draine, 2000)). However, Wolf & Podsiadlowski (2007) argue that the same data, whilst compatible with a mild metallicity dependence of GRB rate/luminosity, would not be consistent with a strong effect.

The chemical abundances of gas in the hosts of GRBs can also be estimated directly via absorption line spectroscopy of the GRB afterglow itself. Again, there could be a bias against higher metallicity, dusty galaxies, since the afterglow must be optically bright to perform this analysis. However, when such abundances have been determined they show a wide range from about 1% solar to nearly solar (eg. Vreeswijk *et al.*, 2004; Prochaska *et al.*, 2007).

2.2   GRB host samples

The immense luminosity of GRBs means that they can be detected in principle to very high redshifts. Thus they can be used to select and characterise galaxies from very early times up to the present.

If the rate of GRB production were the same for all young stellar populations, then GRB host samples should allow us to discriminate the proportions of global star formation arising in different galaxy types, and more generally map the history of star formation in the universe (eg. Wijers *et al.*, 1998; Trentham, Ramirez-Ruiz, & Blain, 2002). As we have discussed above, it seems unlikely that GRBs do trace star formation in a completely unbiased way. However, GRB selection will favour hosts with high star formation rates (and probably, lower metallicities), but otherwise is not biased against small
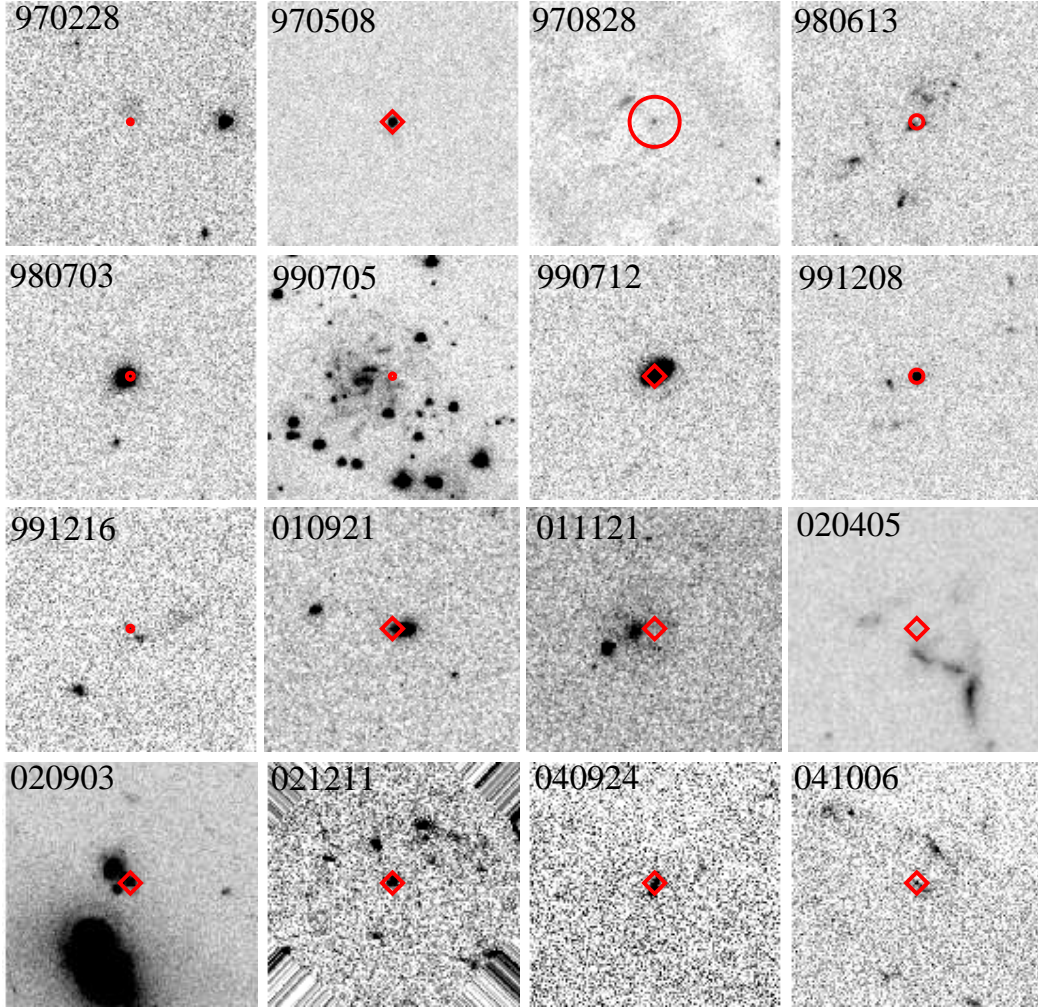
Fig. 1. A mosaic of HST images, each 7.5 arcsec on a side, of the host galaxies of long-duration GRBs with $0.3 < z < 1.0$. Circles are 3σ positional uncertainties on the GRB positions. Where the positions are very well determined (3σ error less than 0.05 arcsec) the position is shown by a diamond.

faint galaxies, which are typically missed in other flux-limited catalogues. Redshifts, metallicities and gas dynamics can be determined in many cases from the afterglow spectroscopy. A good example of this power was GRB 020124, whose host was undetected to $R \sim 29.5$ in HST imaging (Berger *et al.*, 2002), but was found to be a high column density DLA at $z = 3.2$ from the afterglow (Hjorth *et al.*, 2003).

A number of attempts have been made to compare GRB hosts as a whole to other high redshift populations. For example, Jakobsson *et al.* (2005) demonstrated that around $z \sim 3$ the bright end of the host luminosity function is consistent with that expected by weighting by star formation the Lyman-break galaxy luminosity function.
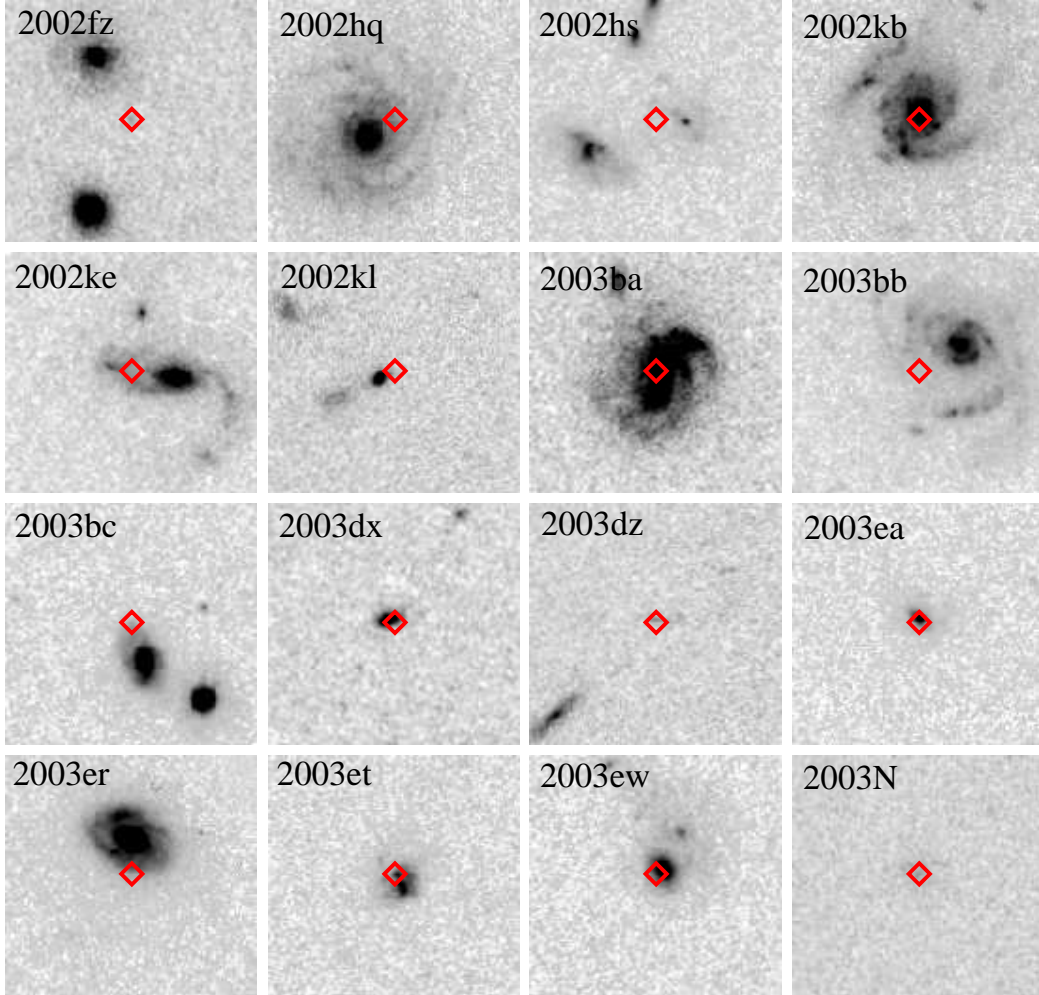
Fig. 2. As with figure 1, but for the hosts of core-collapse supernovae found in the GOODS survey in the same redshift range as the GRBs. The difference between the GRB and SN samples is clear to the eye, with large and grand-design galaxies being more less common amongst the GRB hosts (see Fruchter *et al.*, 2006).

Many authors have noted that whilst occasional bursts have been found in very red (ERO) star-forming galaxies (eg. Levan *et al.*, 2006a; Berger *et al.*, 2007a), the bulk of GRB hosts are sub-L*, blue, low-dust, apparently young galaxies with relatively strong line-emission and a high specific rate of star formation (eg. Fruchter *et al.*, 1999; Le Floc'h *et al.*, 2003; Christensen, Hjorth, & Gorosabel, 2004). Qualitatively these are similar characteristics to the population of galaxies found in emission-line surveys for Lyman-α. An interesting comparison is with the wide area survey of Gawiser *et al.* (2006), for Ly-α emitters around $z \approx 3.1$. In broad terms this population is very like the GRB host sample in the same redshift range, albeit that the Ly-α equivalent width is, unsurprisingly, somewhat higher on the average. Figure 3 shows the cumulative histograms of R-band continuum luminosity (rest frame UV) for this sample together with the published GRB hosts with $2.6 < z < 3.6$, illustrating their
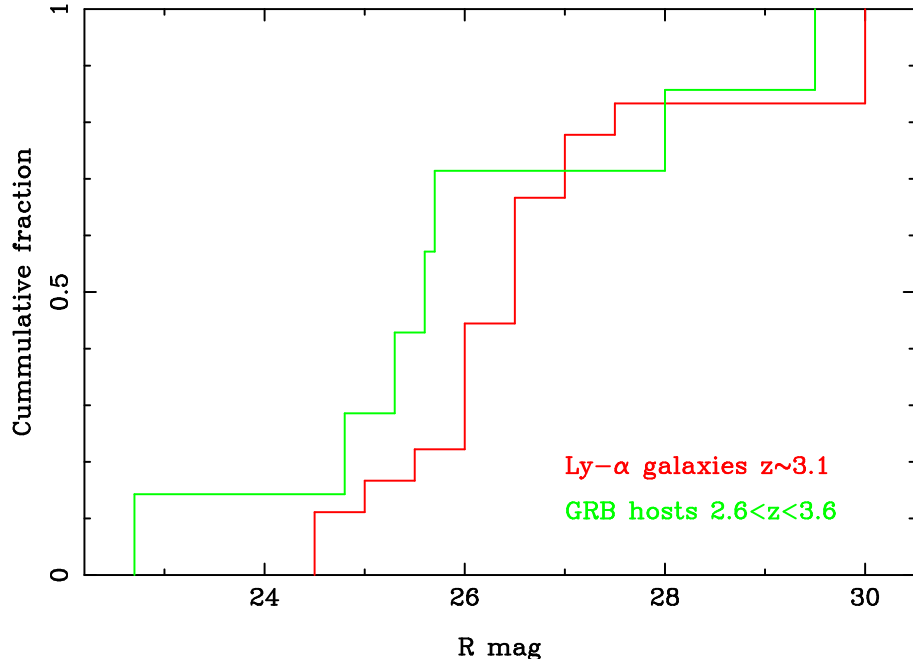
Fig. 3. Cumulative luminosity histograms of broad band R magnitudes for GRB hosts and Lyman-α selected galaxies around $z \sim 3$.

similarity.

3 Short-duration bursts

The first few short-duration GRB afterglows seemed to paint a picture of being in galaxies at redshifts of a few tenths and some of which contained little or no young stellar population. This was widely interpretted as being consistent with the neutron-star neutron-star (or neutron-star black-hole) binary coalescence model for GRB production.

Since then the picture has become murkier. Several apparently short-duration GRBs have been found where the host is hard to identify, and most likely is at much higher redshift $z > 1$. In particular, GRB 060121 had a red afterglow and host galaxy indicating a likely redshift $z > 4$ and almost certainly $z > 1.5$ (Levan *et al.*, 2006b; de Ugarte Postigo *et al.*, 2006). The host and energetics of this burst are much more typical of LGRBs, and the possibility remains that it was actually a member of that class, despite the short duration.

Although in many individual cases there can be ambiguity over whether a given burst should be in the short or long class (Levan *et al.*, 2007b; Bloom *et al.*, 2007), the weight of several likely high-z short bursts has led to speculation that they form a separate sub-class (Berger *et al.*, 2007b). It is worth commenting, though, that so-far all redshifts for short bursts have come from their

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putative host rather than the afterglow, and one consequence of a NS-NS progenitor would be the possibility that the burst occurs well beyond the optical extent of it's host, making definite association unclear in some cases.

3.1 Short-duration bursts from nearby galaxies

In a parallel development Tanvir *et al.* (2005) have shown that there is a weak cross-correlation signal between the distribution of BATSE short-duration bursts and galaxies in the nearby universe. In particular, they used the PSCz galaxy redshift survey, which provides uniform selection over 85% of the sky, and found a positive signal with the sample cut at various recession velocities out to 8000 km s^{-1} (approximately 110 Mpc). Simulations suggested that this level of signal could be produced if between 10 and 25% of BATSE short bursts were coming from nearby galaxies.

These on average must be considerably weaker bursts than those found at cosmological distances. The most likely progenitors are giant flares from soft gamma-ray repeaters. At least one such flare from an SGR in the Milky Way (SGR 1806-20) was bright enough that it could have been detected by BATSE to several tens of Mpc (Palmer *et al.*, 2005; Hurley *et al.*, 2005). In fact, only a very low rate of roughly one per millenium per Milky-Way sized galaxy is sufficient to explain the BATSE observed rate (Levan *et al.*, 2007a; Ofek, 2007).

If of order 10% of BATSE bursts were really from low redshift galaxies it remains surprising that amongst those well-localised by Swift and HETE-II there aren't any clear-cut examples. The best candidate is the weak burst GRB 050906 whose BAT error circle contained the outer parts of an actively star-forming galaxy IC328 at a distance of about 130 Mpc (Levan *et al.*, 2007a), although the spectrum of the burst was significantly softer than previous giant flares. Possibly the softer sensitivity of Swift/BAT and HETE-II compared to BATSE makes it less likely that they will detect SGR giant flares, which, on the basis of only three events, seem to be typically hard (and thermal).

Interestingly, though, there are two candidates for low-redshift short-duration bursts localised by the Inter-Planetary Network (IPN). Specifically, GRB 051103 was determined to have occurred in a thin error region which lay close to the outskirts of the galaxy M81 and at that distance the burst would have been quite consistent energetically with being an SGR giant flare comparable to that from SGR 1806-20 (Ofek *et al.*, 2006; Frederiks *et al.*, 2007). An even more compelling case may be GRB 070201, which was found to overlap the outer part of the disk of M31 (Perley & Bloom, 2007; Hurley *et al.*, 2007). This was an extremely bright burst, and in that regard, again, quite consistent

with a very energetic SGR flare at the distance of M31. The only concern we might have is that two such rare events should occur in neighbouring large spiral galaxies (M31 and the Milky Way) within only two years of each other!

4 Conclusions

The characteristics of their hosts has provided important clues to the nature of GRB progenitors. Several lines of evidence suggest that LGRBs show some preference for lower-metallicity hosts. Particularly at high redshifts GRBs may be the root to identifying and studying low-metallicity star formation, and especially the faint end of the galaxy luminosity function that is generally missed in other surveys. To fully realise the power of GRBs to select high-z populations, it is important that statistical samples of bursts and hosts with redshifts be as complete as possible. As it is, optical/nIR afterglows have been found for nearly 80% of well-positioned Swift LGRBs, but redshifts for only about 50% (Tanvir & Jakobsson, 2007).

Our understanding of the class of short-duration bursts is at an earlier stage, but has seen huge progress in the past two years. Hosts have proved crucial to these breakthroughs, not least because redshifts have yet to be found directly for any short-burst afterglow. By way of illustration of the current, rather confusing, state of affairs, we show in figure 4 a panel of hosts (or candidate hosts) of various short duration GRBs, which range from the very nearby candidates for SGR giant flare bursts, via the intermediate redshift likely NS-NS progenitors, to the new "population" of apparently high redshift short bursts whose nature remains controversial.

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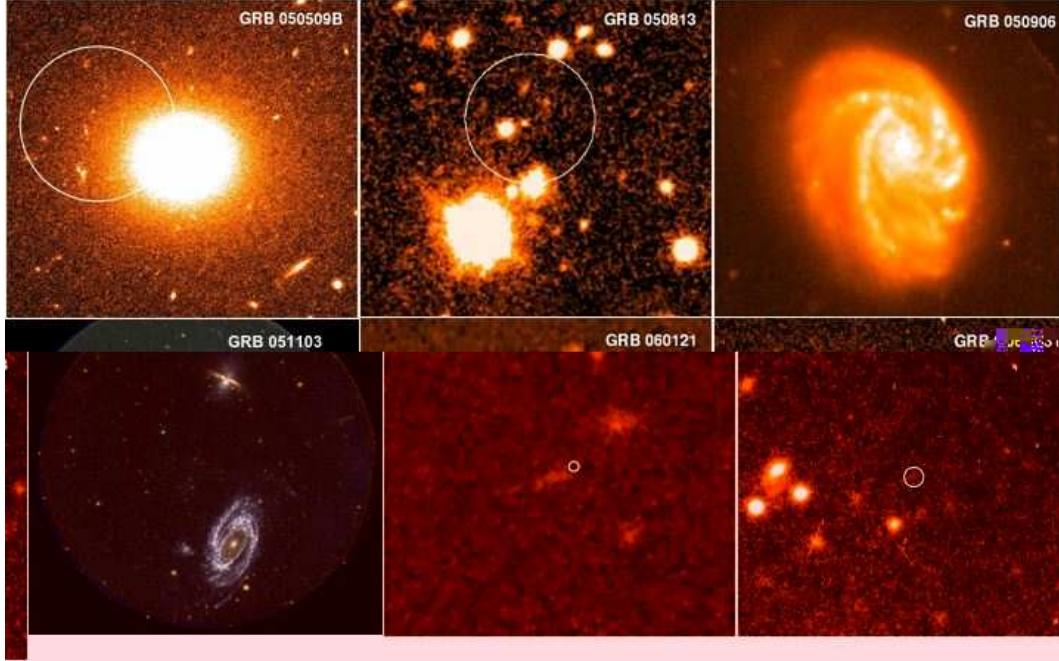
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Fig. 4. Panel showing various (candidate) host galaxies of short-duration bursts. This illustrates the surprising diversity seen to-date, from the moderate-redshift, high stellar mass galaxies expected to dominate for NS-NS progenitors, exemplified by GRB 050509B, to possible low-redshift SGR giant flare events (GRB 050906 and GRB 051103), and the apparently very high redshift cases such as GRB 050813, GRB 060121 and GRB 060313. Note, the size of the images on the sky varies considerably in this panel.

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